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Degasification of Virgin Pittsburgh Coalbed Through a Large Borehole

UNITED STATES DEPARTMENT OF THE INTERIOR

Report of Investigations 7800

Degasification of Virgin Pittsburgh Coalbed Through a Large Borehole

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UNITED STATES DEPARTMENT OF THE INTERIOR
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DEGASIFICATION OF VIRGIN PITTSBURGH COALBED THROUGH A LARGE BOREHOLE

by

H. H. Fields,[1] Stephen Krickovic,[2] Albert Sainato,[3]
and M. G. Zabetakis[4]

ABSTRACT

The Bureau of Mines is in the process of degasifying a virgin area in northern West Virginia from the base of an 839-foot-deep vertical borehole. An in situ gas pressure hole 199 feet long, and seven degasification holes ranging in depth from 500 to 850 feet (average 618 feet) were drilled in an 8-foot-thick virgin Pittsburgh coalbed from the enlarged (14-foot-diameter) bottom of this borehole. The in situ pressure at the back end of the hole and the range of gas and water flows from degasification holes as they were completed and closed off were 203 psi, 79,000 to 257,000 cfd (average 160,000 cfd), and 5 to 8 gpm per hole (average 6.8 gpm), respectively. Twenty-four hours after the seven holes were connected through individual water traps to a common collector for natural venting of the gas through pipes to the atmosphere, the total gas and water flows and the in situ pressure dropped, respectively, to 971,000 cfd, 1.3 gpm, and 18 psi. Eighty days later the corresponding values dropped to 529,000 cfd, 0.50 gpm, and 13 psi.

After 180 days of degasification, 91 million cubic feet of gas had been removed from the affected virgin area. This represents 60 to 70 percent of the gas calculated to be contained in the area of coal affected by the holes.

INTRODUCTION

The Bureau of Mines has been responsible for the promotion of health and safety in mining since its establishment in 1910. Presently, in addition to other areas of research, it is engaged in methane control involving removal of methane from virgin coalbeds, from major panels being pillared, and from old gobs. Specifically, this study is an attempt to determine the effectiveness of long holes drilled in solid coal in degasifying a very gassy virgin area of the Pittsburgh coalbed.

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[1] Mining engineer.
[2] Supervisory mining engineer.
[3] Mining engineering technician.
[4] Supervisory research chemist.

Methane exists under pressure in micropores, joints, and fractures of gassy coalbeds. In many mines it also is present in adjacent strata at various distances above and below the coalbed. An in situ gas pressure of 275 psi has been measured in the Pittsburgh coalbed, and the permeability of this bed has been found to be high compared to that of other coalbeds.[5] Further, in a number of mines where gas wells are located in this coalbed, significant bleed off of methane through the well barrier has been found.[6] However, because of the high in situ gas pressure and permeability of the Pittsburgh coalbed, considerable degasification can be effected over a significant area if accomplished ahead of mining. The procedure considered in the present study involves the drilling of long holes in the coalbed from the enlarged bottom of a borehole; the gas then is bled through a piping system to the surface and vented (or utilized).

Despite the use of methane detectors mounted on continuous miners for automatic disconnection of power at 2 percent methane concentration, ignitions do occur at the face and create an explosion hazard. Additionally, resultant stoppages reduce the productive time; this in turn reduces the rate of advance in mining with consequent lower production and higher costs. The handling of methane in the development of very gassy coalbeds with ventilation air alone in compliance with the 1969 Act is extremely difficult, if not totally impractical with existing technology. While the drilling of degasification holes in a coalbed from the outside headings in one or more sets of main headings being developed into virgin areas has been attempted in a number of mines over the past 12 to 15 years,[7] apparently the technique described in this paper has not been undertaken in this country.

ACKNOWLEDGMENTS

The cooperation of the management of Eastern Associated Coal Corp., Pittsburgh, Pa., management of the Federal No. 2 mine, and contractors Fenix & Scisson and Loffland Bros., Tulsa, Okla., and Sprague and Henwood, Scranton, Pa., is greatly appreciated.

THE MULTIPURPOSE BOREHOLE

The borehole utilized in this study is located in the barrier pillar 130 feet east of the outside heading of a projected set of 10, 3 South Mains headings. Figure 1 shows the location to be approximately 1 mile from the existing faces of 3 South Mains. The borehole has been designated as being

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[5] Cervik, Joseph. An Investigation of the Behavior and Control of Methane Gas. Min. Cong. J., v. 53, No. 7, July 1967, pp. 52-57.

[6] Zabetakis, M. G., T. D. Moore, Jr., A. E. Nagel, and J. E. Carpetta. Methane Emission in Coal Mines: Effects of Oil and Gas Wells. BuMines RI 7658, 1972, 9 pp.

[7] Poundstone, W. N. Private communication, 1973. Available upon request from Stephen Krickovic, Bureau of Mines, Pittsburgh, Pa.

Spindler, G. R., and W. N. Poundstone. Experimental Work in the Degasification of the Pittsburgh Coal Seam by Horizontal and Vertical Drilling. Trans. AIME, v. 220, 1961, pp. 37-46.

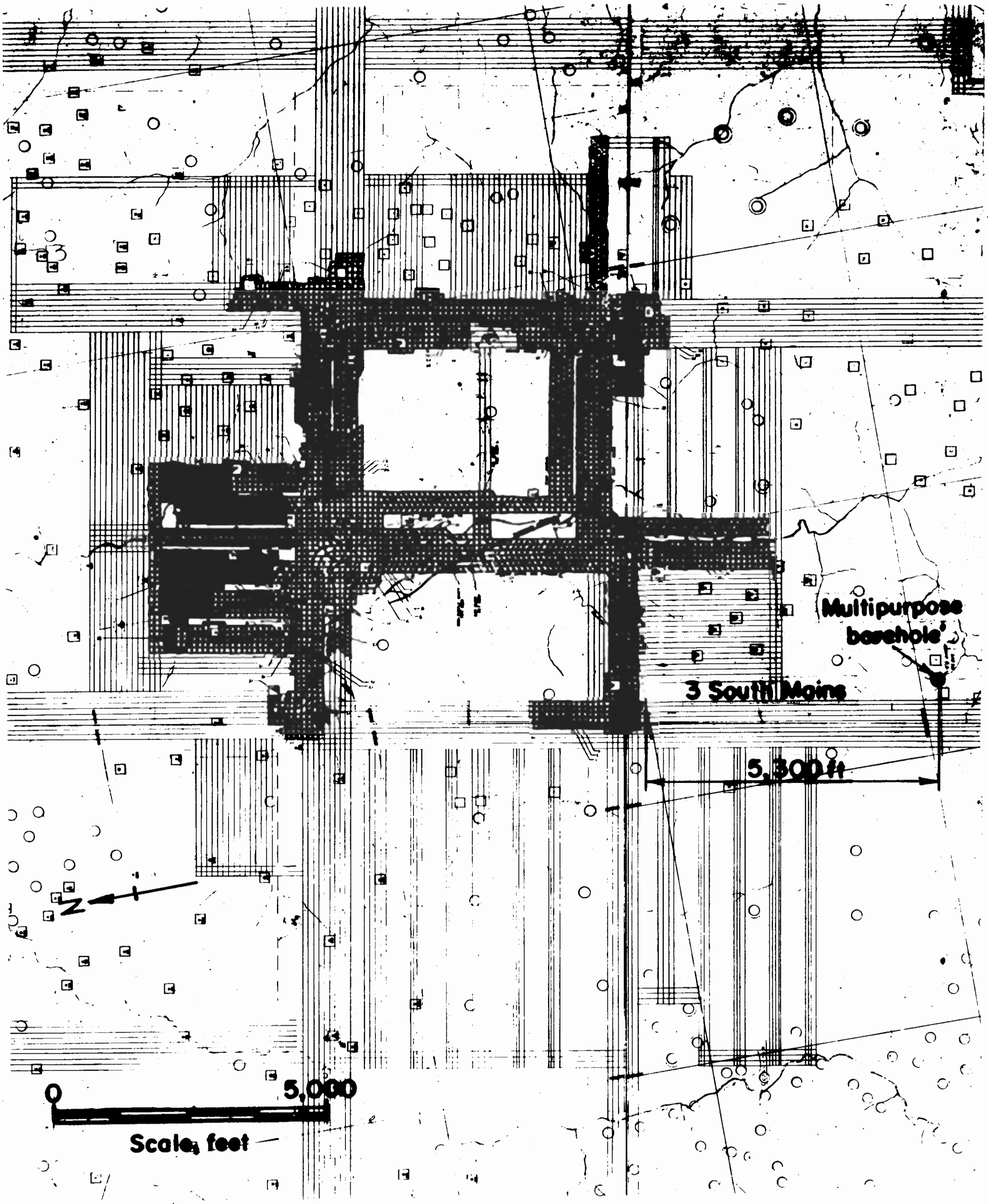

FIGURE 1. - Location of multipurpose borehole in virgin Pittsburgh coalbed.

multipurpose because after completion of degasification, or when 3 South Mains headings have been developed to the borehole, it may be used as an intake airway and later as a return airway. Still later, when the pillar line has been established, the borehole can be used to degasify the gob area nearby. While serving as an intake airway, the borehole may be used as an escapeway in an emergency, with power cables and communication lines installed in the two degasification pipes located outside of the 48-inch-OD casing.

Vertical Drilling Operations

The multipurpose borehole was drilled with a specialized rig. All major components of the drilling assembly and supporting equipment are listed in the appendix. Views of the drilling rig and mud and clarification ponds are shown in figures 2 and 3.

After preparation of an access road, a standard NX core hole was drilled at the center of the multipurpose borehole location to determine the character of the superjacent strata, the thickness of the coalbed, and the depth to the bottom of the coalbed. Figure 4 shows the core hole record which the driller used as a guide in determining the extra weight required on the bit at each change in competence of strata. Upon completion of the coring operation, a 200- by 100-foot site was prepared and graded for drainage, 480-volt ac power was provided, and the drilling rig was erected to drill an 84-inch-diameter borehole. This diameter was drilled at approximately 10 rpm to firm rock (50-foot depth), utilizing reverse-mud air-assist circulation. Two 60-inch Do-nuts (23,400 lb)[8] were used on the 7,500-lb drill bit and 16,400-lb, 84-inch stabilizer to provide the necessary cutting pressure; a single shot deviation survey was made.

Two rolled and welded sections of 74-inch-ID casing (lower 30 feet with 5/8-inch wall thickness and upper 20 feet with 1/2-inch wall thickness) were placed in the hole on firm rock. Type II cement, plus 2 percent calcium chloride mixed with 5.2 gallons of water per sack of cement, were pumped in the annulus through two strings of 2-inch tubing to a height of 5 feet both in the casing and the annulus. After waiting 8 hours for the cement to harden adequately, the second grouting stage was undertaken in the same manner as for the first stage, and completed to the top of the ground where a concrete pad had been poured prior to start of drilling. A total of 170 sacks of cement were used in the first stage and 380 sacks in the second. The upper 45 feet of casing had a safety factor of 2 against hydrostatic head, with an assumed mud weight of 8.8 lb per gallon. This 50 feet of 74-inch casing was installed to prevent entrance of surface water into the hole.

Drilling of the 72-inch-diameter borehole was undertaken within the 74-inch casing, and continued to the bottom of the Pittsburgh coalbed (789 feet), again utilizing reverse-mud air-assist circulation with the mud weight maintained from 8.5 to 9.5 lb per gallon--average viscosity of 30 seconds flow. A geolograph was installed to record depth, time, and rate of penetration.

[8]Use of trade names or makes and models of equipment is for information only and does not constitute endorsement by the Bureau of Mines.

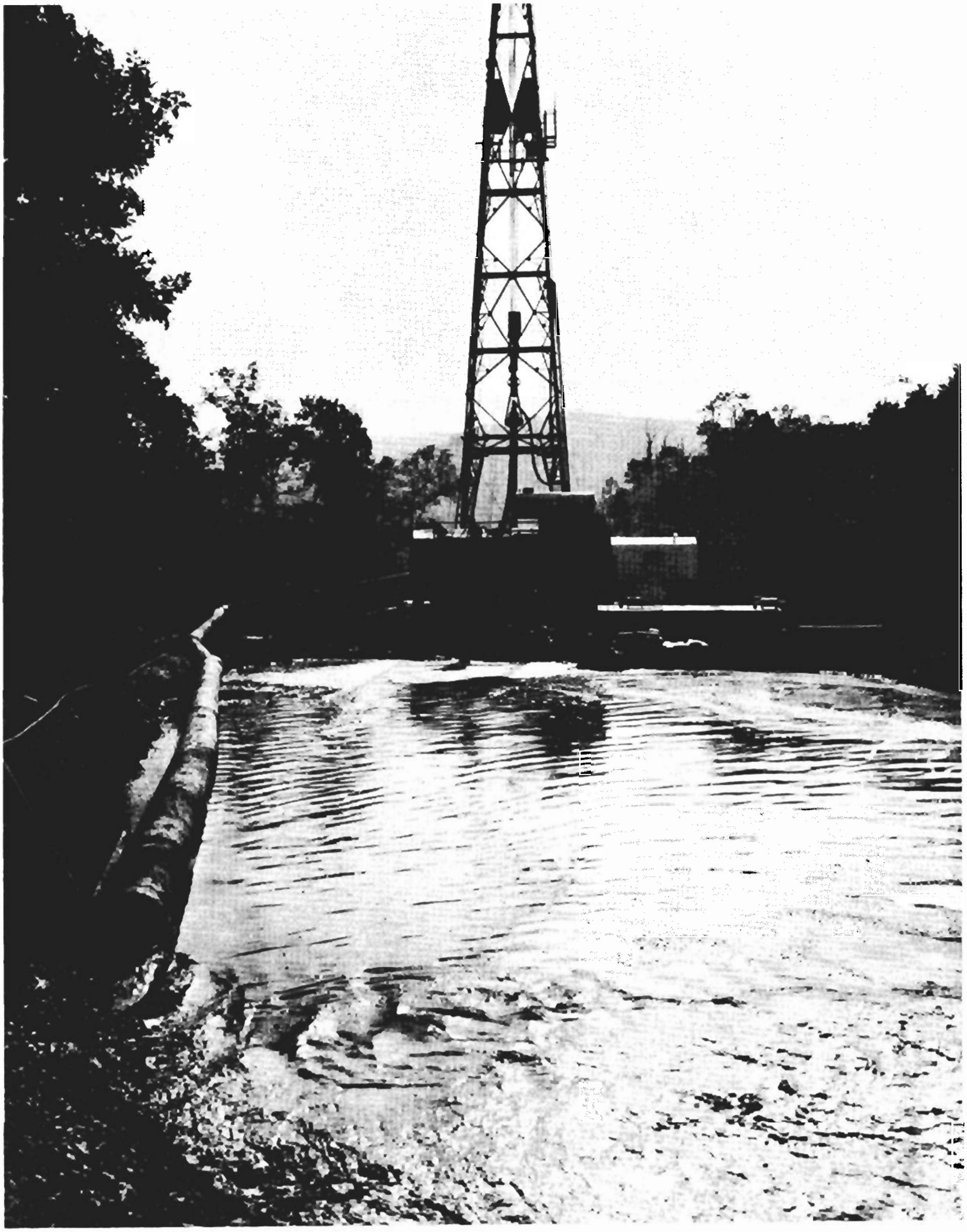

FIGURE 2. - Assembled drilling rig with mud pond.

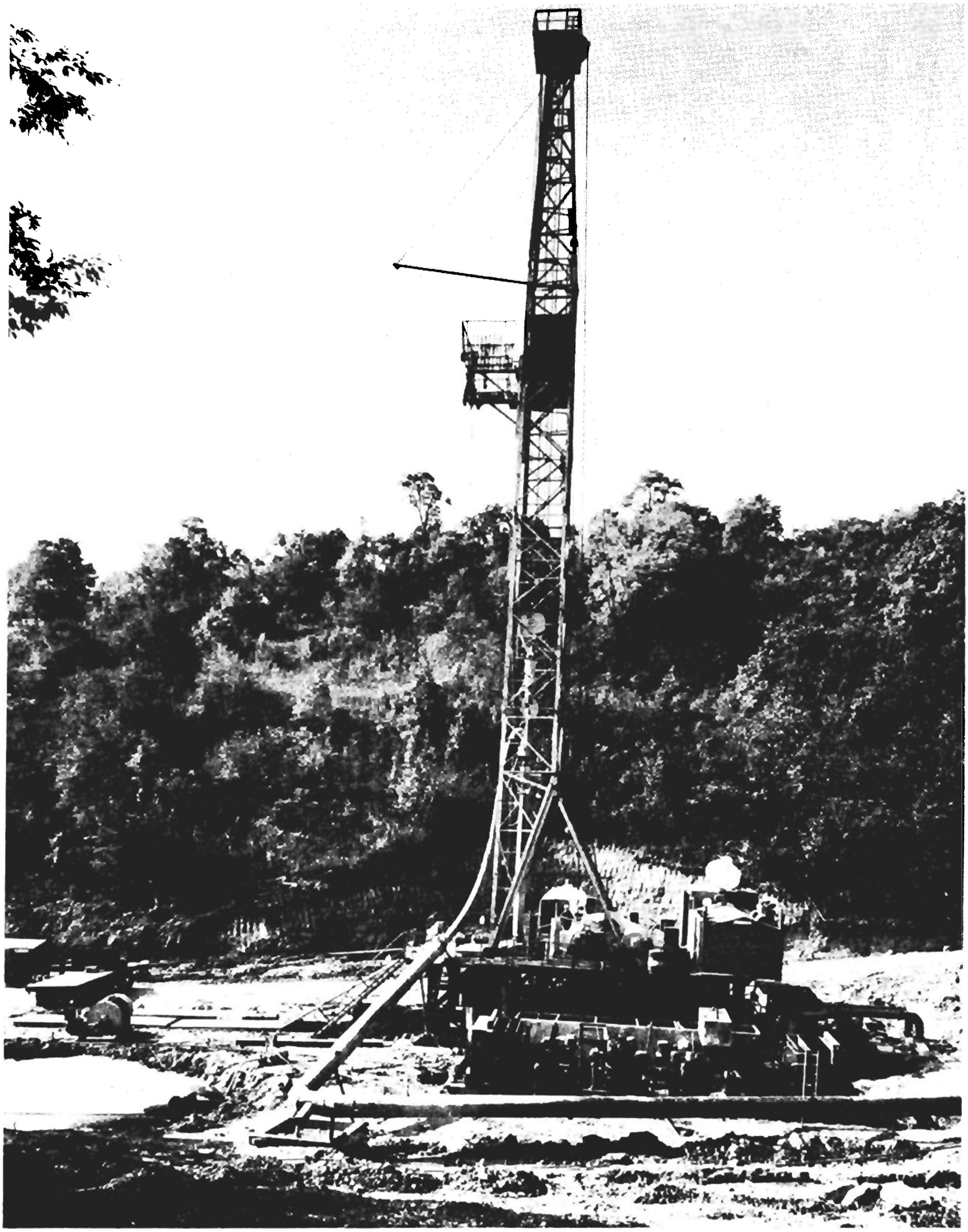

FIGURE 3. - Assembled drilling rig with clarification pond.

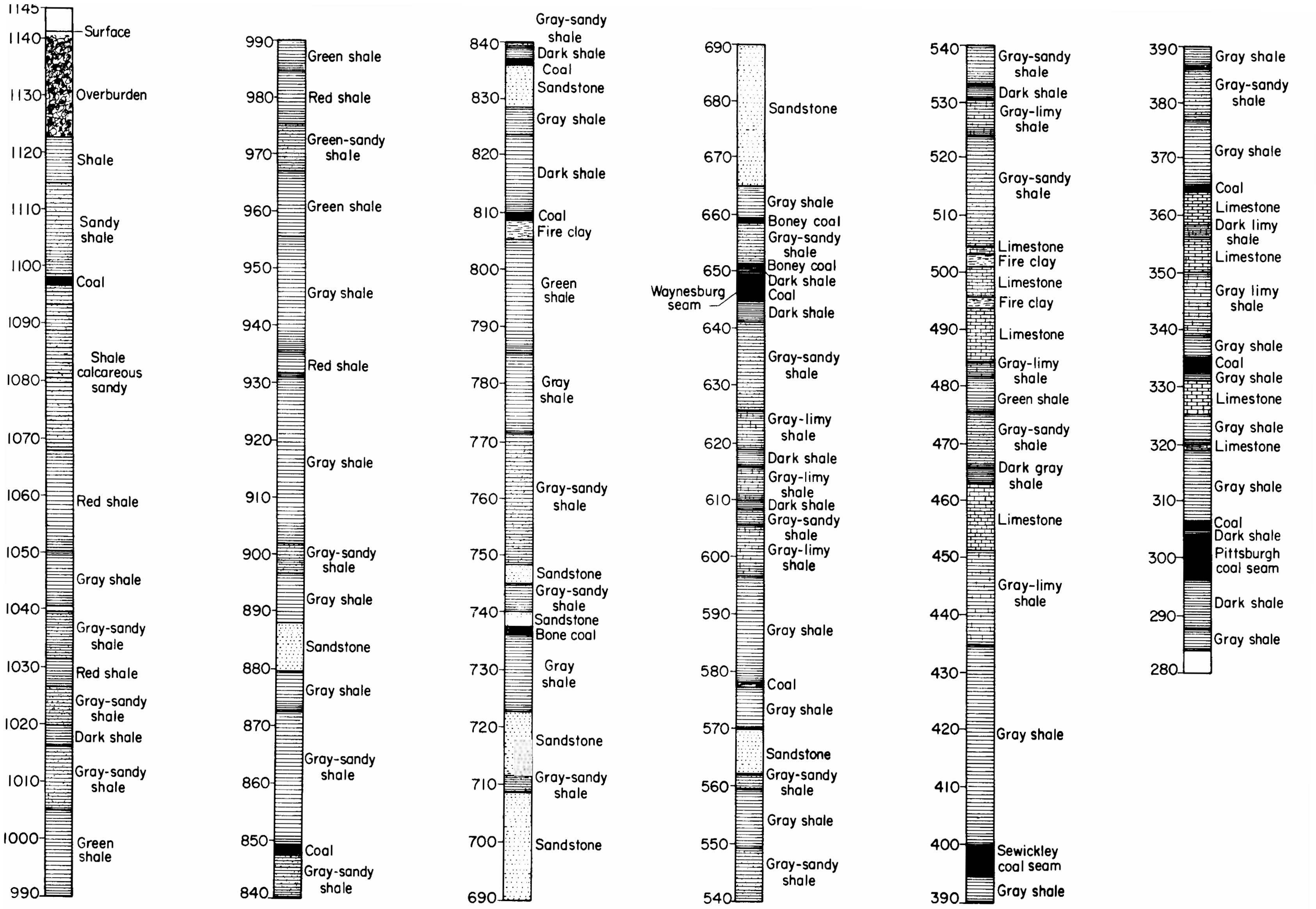

FIGURE 4. - Core hole record at center of multipurpose borehole location.

Single-shot directional surveys were run at each 30-foot depth drilled, with a Dowell sonar survey run at completion of drilling to obtain the exact direction and the amount of deviation from the vertical. The deviation was 19 inches at the depth of 839 feet.

In drilling the 72-inch hole, two separate 72-inch stabilizers (16,400 and 8,400 lb); one 60-inch collar stem (19,500 lb); 10 Do-nuts (117,000 lb); one holddown clamp (800 lb); and the 72-inch drill bit (7,500 lb) were used. The rpm (approximately 10) and Do-nut weights were varied with competence of rock strata. Some difficulty was encountered in the upper strata of soft shales and fire clays from compaction of the soft material between the cutters. It was necessary to withdraw the bit and replace the cutters with a type more suitable for the conditions. Drilling operations were continued 24 hours per day, 7 days a week; the 72-inch hole was drilled in 54 calendar days. The drilling mud with the cuttings was discharged into the upper large pond (fig. 2) from which a ditch was dug approximately 20 feet from the lower end to decant the water and some mud to the clarification pond (fig. 3).

Placement and Grouting of Casings

The 48-inch-ID steel casing was fabricated in 50-foot lengths from ASTM 283-58, grade C steel in accordance with ASME Boiler Code Section VIII, division 1 specifications. The casing was designed to withstand full hydrostatic head, using the formula:

$$P\ (\text{psi}) = \frac{2\ E}{1-\lambda^2}\left(\frac{t}{D}\right)^2$$

where P = hydrostatic pressure,

E = modulus of elasticity,

λ = Poisson's ratio,

t = wall thickness (inches),

and D = outside diameter (inches).

A safety factor of 2 was maintained, allowing for 1/4-inch "out of roundness" and for presence of drilling mud within the casing.

As the casing was lowered in the hole, arrangements were made to hold a section or sections at the top while the next section was welded. Welding was performed by the submerged arc fusion method; all field welds were X-ray inspected. Shop welds were inspected at random. Iridium 192, with a half-life of 75 days, was used for the radiographic inspections.

Prior to placement of the casing in the hole, centralizers, two 4-inch-diameter gas pipes, two 3-inch conduits (one for power and communications and one for water pumping system), and 1/4-inch-thick steel plate to provide a segment for an air duct were welded onto the 48-inch casing (fig. 5).

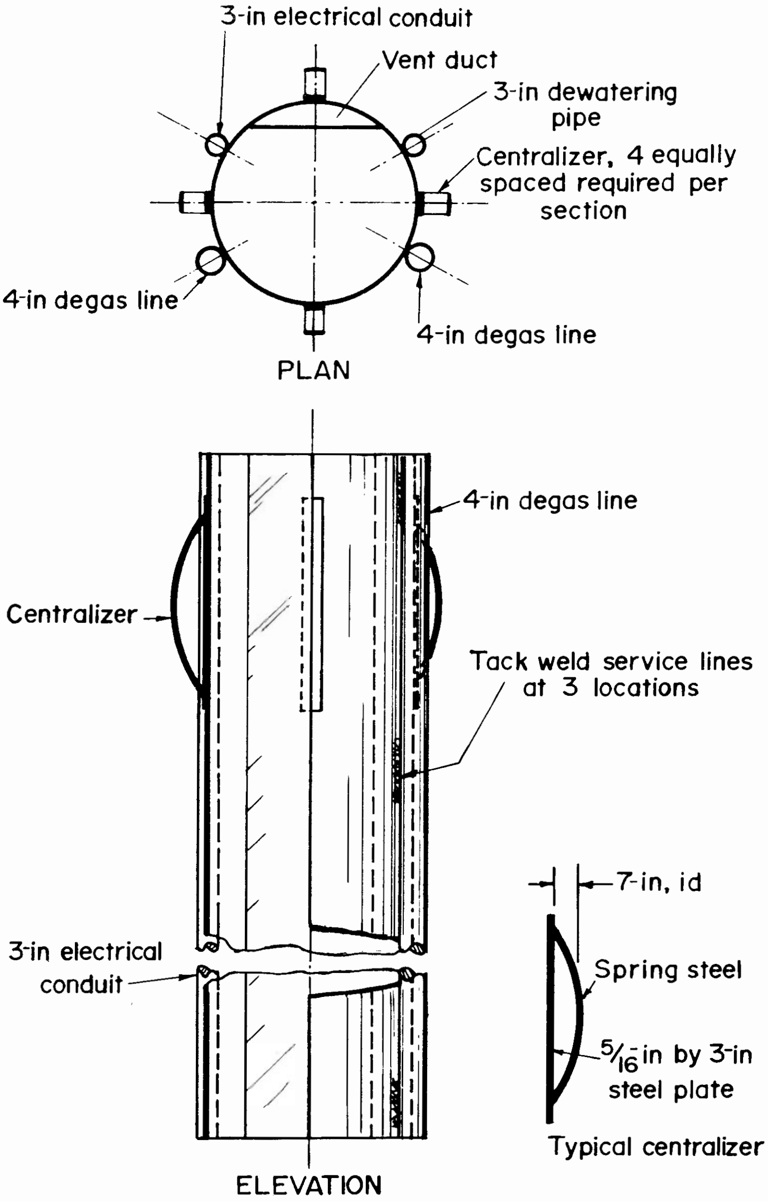

FIGURE 5. - Arrangements of centralizers, gas pipes, power conduits, and steel plate for air duct on 48-inch casing.

Threaded bull plugs were installed in the bottom of the pipes to prevent cement from entering them and to facilitate removal for use of the pipes as planned.

After the casing, with all its accessories (394,000 lb), was suspended within 16-1/2 feet of the coalbed bottom (826 feet with 3 feet above ground), sand and gravel were dropped through the drilling mud to the bottom of the 72-inch hole to form a layer 10 feet deep. Bags of sand were then dropped to raise the layer an additional 10 feet, and thereby provide a landing for the 48-inch casing. The casing was raised and lowered slightly to form a good seal against entrance of cement slurry during the subsequent grouting operation, and to form a platform for enlargement of the borehole bottom. A "hemihead," with a 2-inch relief valve and a 1-inch connection for a pressure gage, was welded to the top section of the 48-inch casing to prevent grout entering inside the casing which was filled with drilling mud. The predetermined excess safe pressure within the casing was computed to be 34 psi.

The drilling mud was washed out from the annulus by pumping through three equally spaced 2-inch pipes followed by 40 barrels of "drill flush" to a height of 120 feet from the bottom of casing. This section was grouted immediately through the same 2-inch pipes with cement slurry equal in specifications to that used in grouting 50 feet of the 74-inch casing at the top of the borehole. After the 2-inch pipes had been raised from the bottom of the 48-inch casing and the grout allowed to set for 16 hours, drilling mud in another section of the annulus was removed and the section grouted as already explained. The grout had to be sufficiently firm to prevent the 2-inch pipes from penetrating it, and the pressure of the new grout provided the necessary seal at the joint. An identical procedure was followed in removing the drilling mud and grouting the remaining annulus in two more stages. The four stages were of variable lengths, with each upper one being longer due to a reduction in the hydrostatic head. The maximum pressure recorded on the hemihead was 30 psi, and the hemihead was removed after the first stage was grouted.

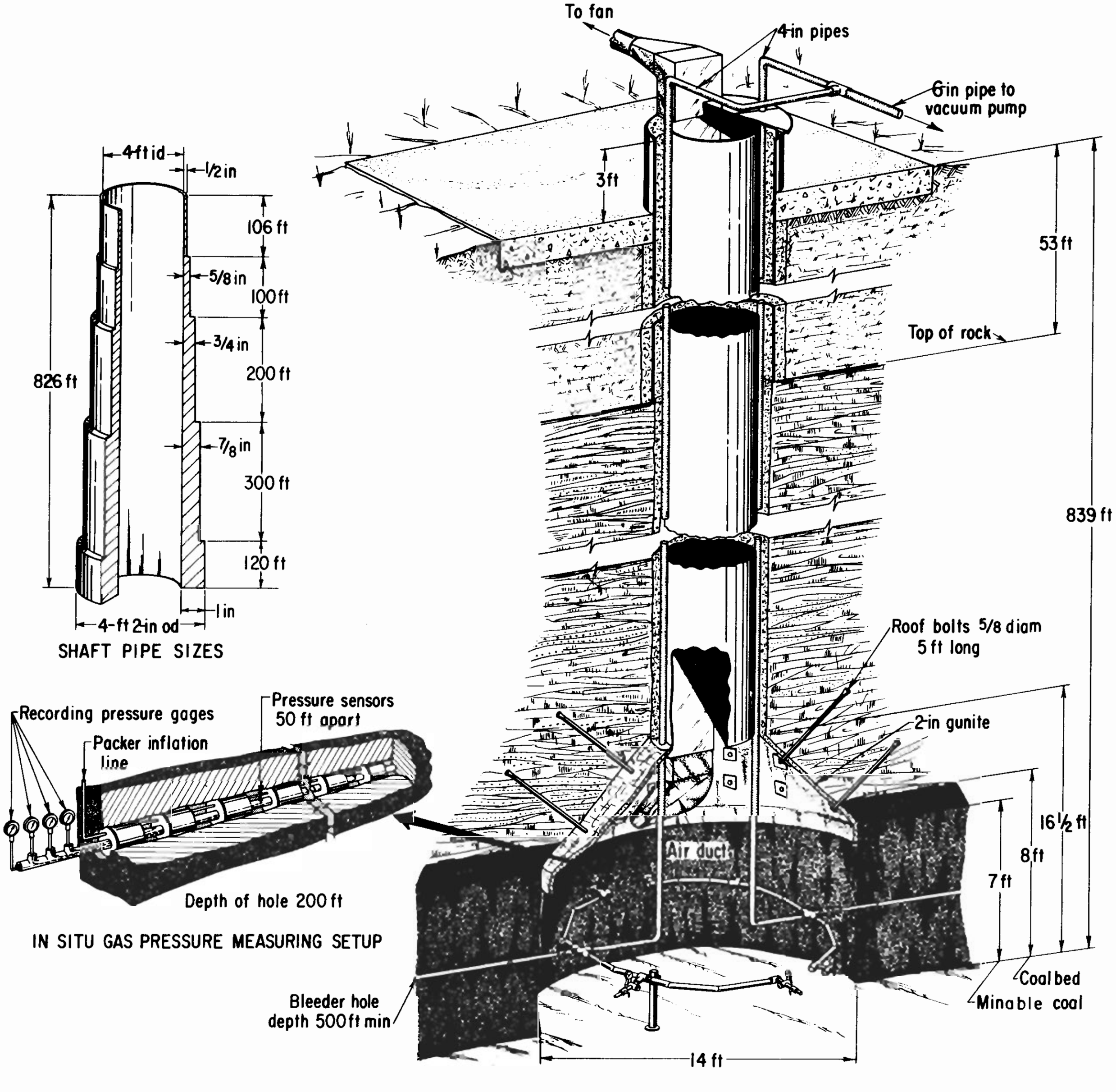

FIGURE 6. - Perspective view of completed multipurpose borehole.

Ventilation and Hoisting Facilities

Figure 5 shows the segment of the 48-inch casing arranged for the ventilation duct; figures 6 and 7 show the total ventilation duct in perspective of the multipurpose borehole with adapters on top and bottom, and details of the enlarged bottom of borehole, respectively. Figures 8 and 9 show the locations of the ventilation, hoisting, and gas pumping facilities on the surface.

A Buffalo type CB blower was installed for exhausting duty in a steel building, together with a 40-hp, permissible ac motor and control, and a V-belt drive to obtain a maximum air volume of 9,000 cfm at 12-inch water gage.

All hoisting was accomplished by a single drum mine hoist (30-inch diameter by 24-inch face with 6-1/2-inch flange), model S-4000-300 manufactured by the Coeur d'Alene Co., Spokane, Wash. The hoist was powered by a permissible 50-hp motor; with the power transmitted through a Sanstrand flow pump and a Houdaille piston-type hydraulic system. It has a capacity of 8,000 lb, and was equipped with 7/8-inch rope, overspeed, override, automatic braking facilities and simplex controls. All hoisting equipment was housed in a steel building.

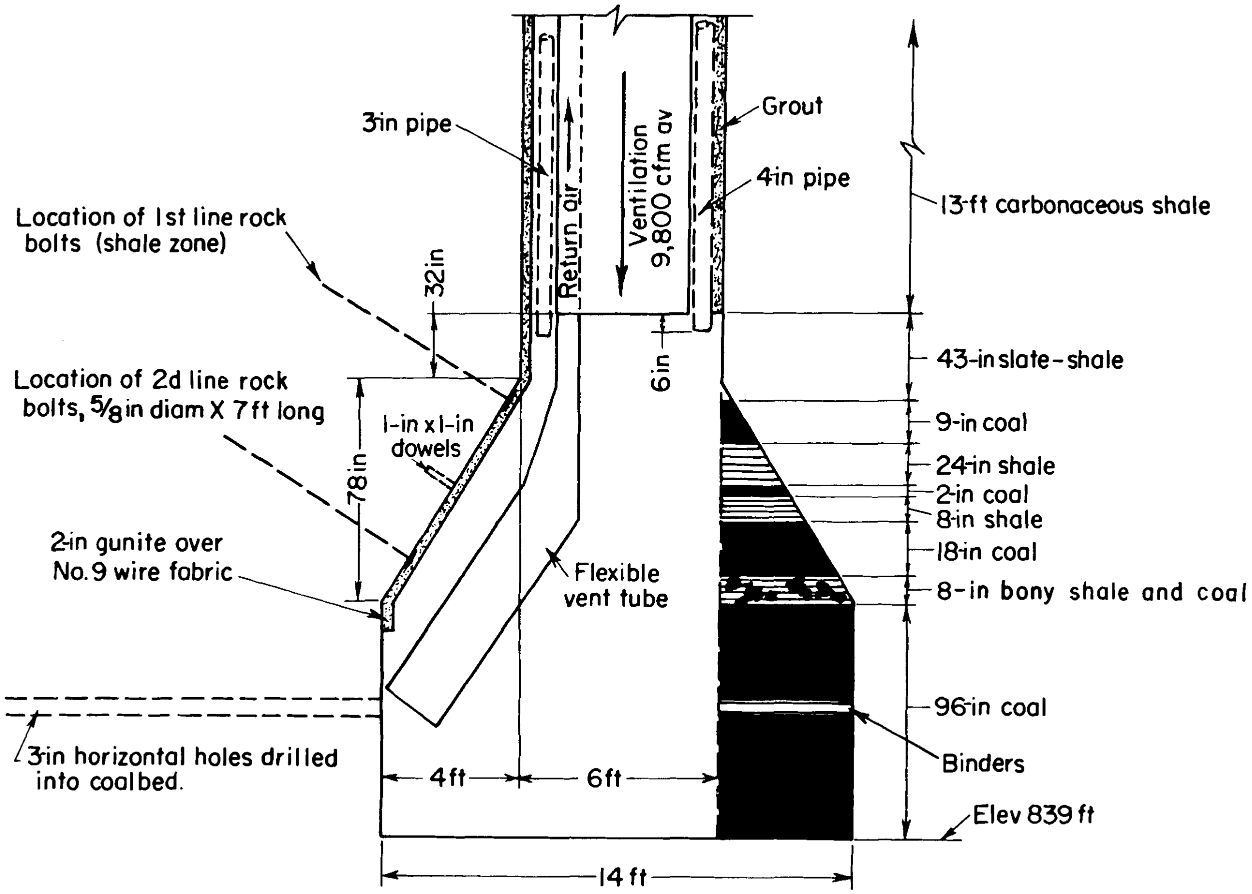

FIGURE 7. - Details of enlarged bottom of borehole.

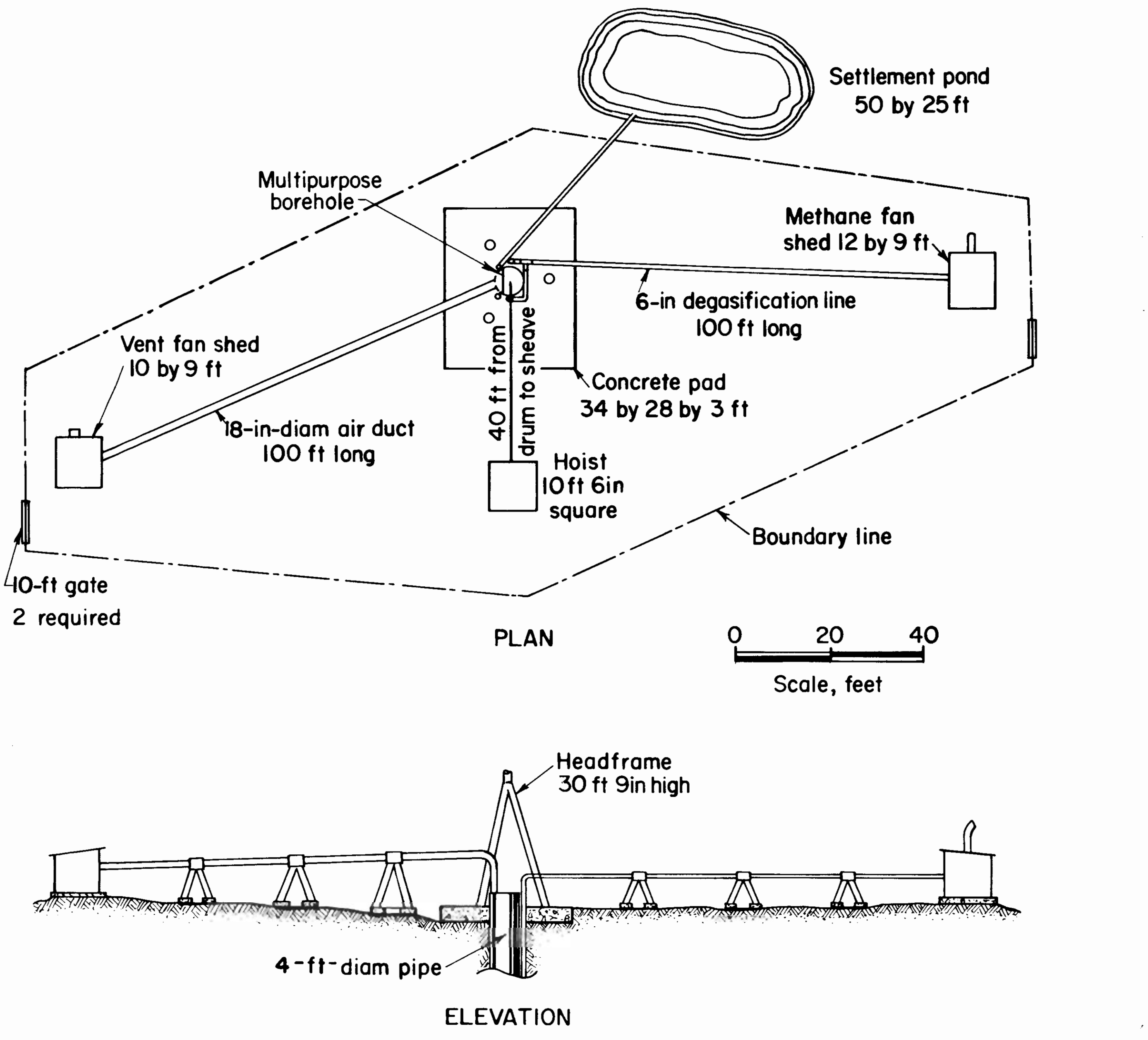

FIGURE 8. - Surface plant layout of multipurpose borehole.

A tripod headframe fabricated from Schedule 80 steel pipe, having two legs 6-5/8 inches and the third leg 8-5/8 inches in diameter, was installed over the borehole. The pulley was located 30 feet 9 inches above the top of the concrete pad and 40 feet from the hoist drum. The headframe was anchored to the concrete pad, 20 by 20 by 3 feet thick (figs. 8 and 9). All hoisting facilities were constructed to meet the requirements as set forth on page 36 of the Mandatory Safety Standards, Underground Coal Mines, Title 30, Code of Federal Regulations, Part 75, March 30, 1970-December 31, 1972.

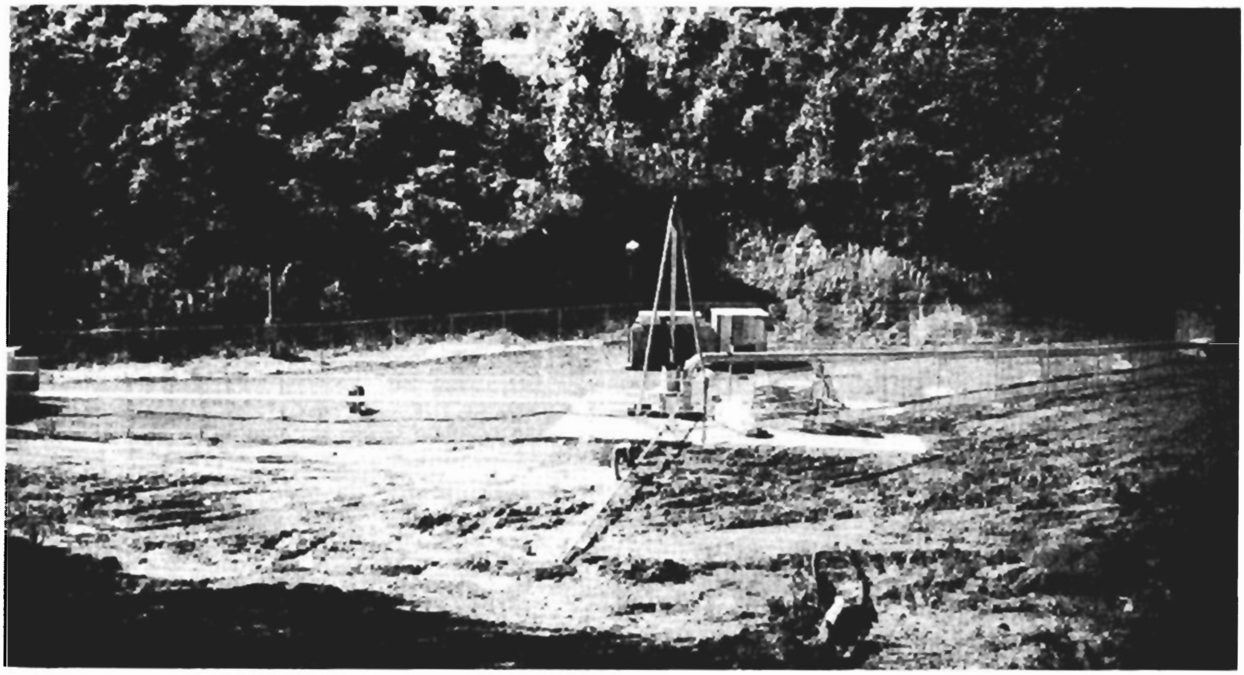

FIGURE 9. - Photograph of the surface plant.

Horizontal Drilling Operations

Before the drilling operations could be undertaken in the coalbed, the bags of sand and the gravel were removed by hand loading into a 36-inch-deep, steel shaft bucket, especially constructed to fit within the available space in the 48-inch casing. Progressively, as these materials were removed, the borehole was enlarged on a 34° angle to a 14-foot diameter on top and bottom of the coalbed. All excavation was done with pavement breakers and chipping hammers for safety reasons. During this operation, water was usually pumped to the surface by a deep well pump and, at times, by bailing into the hoisting bucket. Also, the ventilation duct adapter was installed and reinforced flexible tubing attached to it for movement to each hole as drilling was started. The sloping rock section was bolted with 5/8-inch-diameter, 7-foot-long, steel bolts drilled on 4-foot centers on two circumferential lines (figs. 6 and 7), and coated with a 2-inch-thick layer of reinforced gunite. Because the coal surface area was wet continuously, it was not gunited. The ventilation facilities were adequate to maintain methane concentration under 1 percent during drilling operations. All work so far described below the 48-inch casing was performed in two 10-hour shifts 6 days a week for approximately 12 weeks.

The degasification holes were drilled in the coalbed with a Sprague and Henwood model 40CL drilling machine powered by a 20-hp Ingersoll-Rand air motor through a standard four-speed gear box. The machine base was anchored to bolts drilled in the coalbed near the bottom in the direction of drilling. Control of torque, drilling speed, and thrust was not possible with this unit.

Hughes "Blue Demon," series 200 carbide insert bits were used for drilling, except when NX diamond core bit was needed. For the most part, NX, AX, and BW rods were used in drilling. All holes were started in the coalbed with an NX diamond bit inclined upward 0.25° at a point approximately 34 inches below the top of the coalbed. Coring continued to a depth of 55 feet, using 15 feet of 2-7/8-inch tubing behind the coring bit to minimize deflection. A coring bit set with diamonds was used to provide a smooth penetration through minor iron pyrite lenses present in a zone 18 to 24 inches below the top of the coalbed. An NX size insert-type, replaceable blade drag bit fitted directly to a 10-foot packed hole stabilizer, 2-29/32 inches in diameter, followed by a 10-foot drill rod and a 5-foot packed hole (2-29/32 inches in a 3-inch hole) stabilizer was used from 55 to 100 feet in depth (fig. 10).

When hydrostatic water level readings indicated that the hole was penetrating downward at a depth of 100 feet, a survey was made with a Tro-pari compass and the degree of downward deflection obtained. The stabilizer assembly then was changed to a single packed hole stabilizer, 5 feet in length, immediately behind the same drag bit.

All holes, except for the 199-foot-deep in situ gas pressure hole, were advanced with this assembly to about 390 feet, with surveys being made generally at 150, 300, and 400 feet. In some cases, a downward deflection of 1° was indicated. Since the Tro-pari instrument is accurate only to within 0.5°, correction to a horizontal or upward inclination was desirable. At a depth of

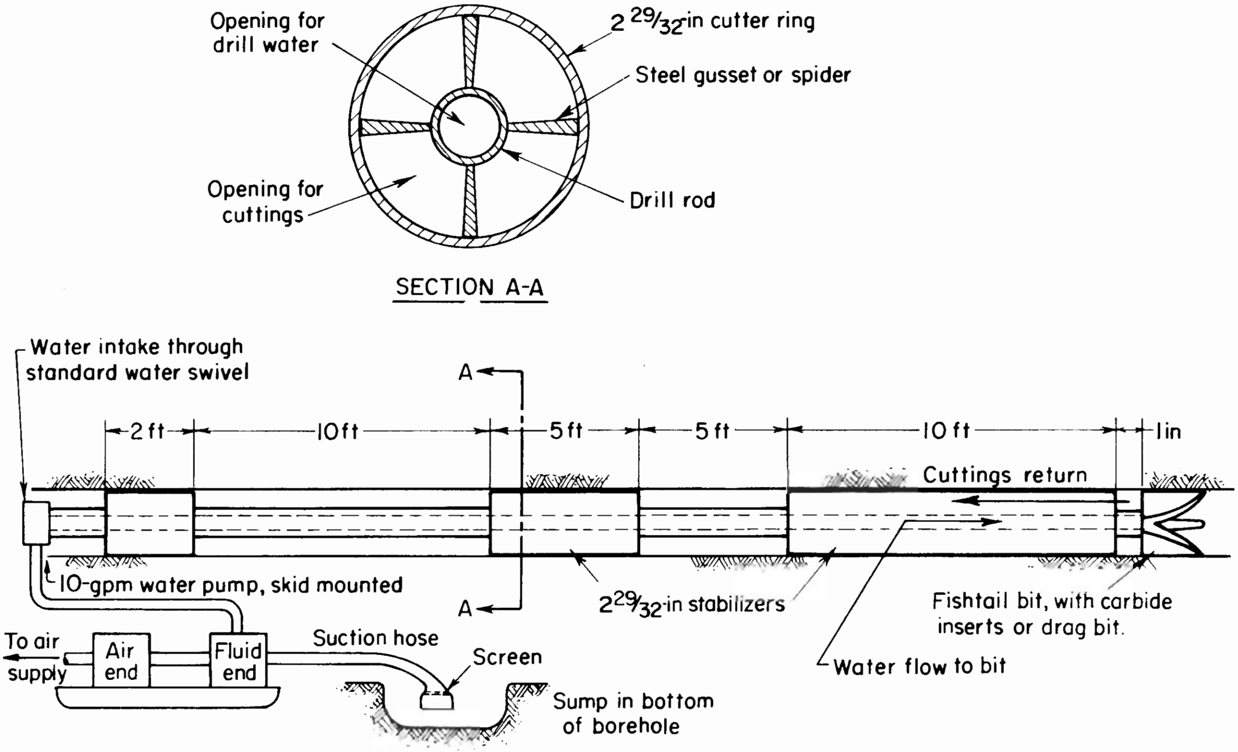

FIGURE 10. - Drilling assembly for holes in coalbed.

approximately 400 feet, the 5-foot packed hole assembly was followed by a weighted 5-foot length of 2-1/2-inch drill rod and the hole advanced to a depth of 500 feet. The surveys at the 500-foot depth normally indicated a slight upward inclination.

Surveying beyond 500 feet was not considered economical because of the time required to replace the rods and stabilizers. All holes, except one, were advanced beyond 500 feet, assuming only minor characteristic deviations would be realized by using the two basic stabilizer assemblies described above.

Behavior studies of the 10-foot stabilizer, followed 10 feet behind with a 5-foot stabilizer, indicated the bit would drop between 1 and 2 feet in approximately 150 feet, and a single 5-foot stabilizer would cause a 1- to 1.5-foot rise in approximately 100 feet. The holes were advanced in excess of 600 feet using the two-unit stabilizer assembly (fig. 10), then changed to the single stabilizer assembly; one hole was drilled to a maximum of 850 feet. The bit stopped advancing at the 850-foot depth and drilling was stopped and no further advance was made due to high costs involved to advance beyond this point with the equipment used. No rock cuttings were evident, and if the response anticipated in the stabilizer action was correct, the hole had stopped in the upper third of the coalbed. It is possible that local concentrations of pyrite lenses could have been encountered in that zone.

During the drilling of each hole, a flexible tubing attached to the adapter at the bottom of the main air duct (segment of 48-inch casing), was extended to the hole with approximately 9,000 cfm of air conducted to the work area. Methane concentration in the discharge of the exhauster never exceeded 1 percent. Upon completion of each hole, a Bureau-designed mechanical packer (fig. 11) was inserted in the hole and the hole was shut in to prevent outflow of gas until all degasification holes were completed. The in situ pressure

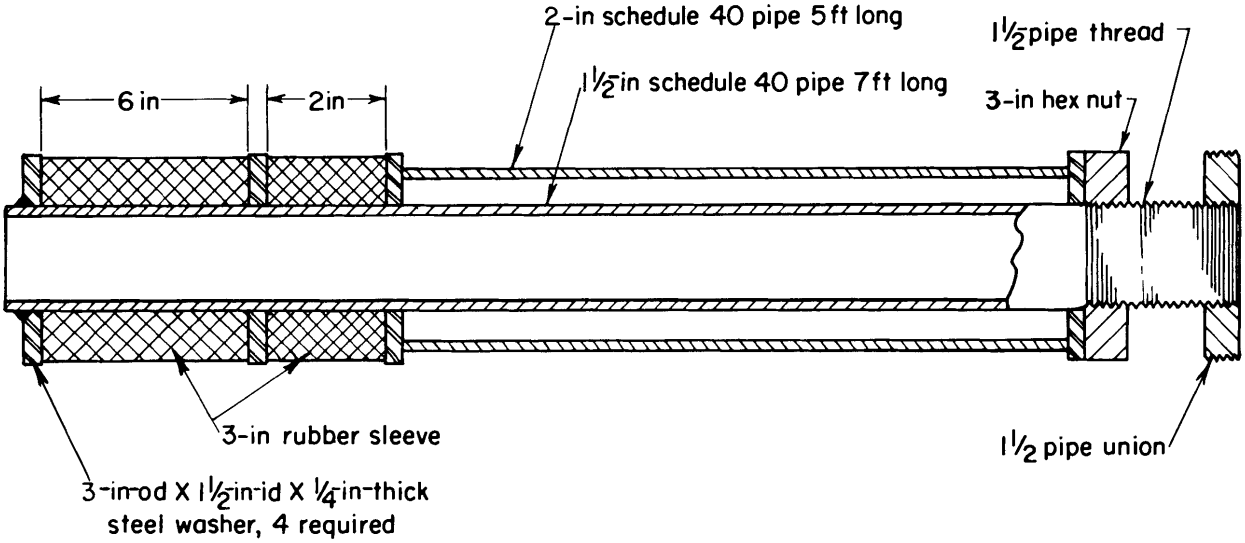

FIGURE 11. - Mechanical packer assembly for holes in coalbed.

hole was sealed as shown in figure 6, with provision for measuring the gas pressure at four equally spaced locations.

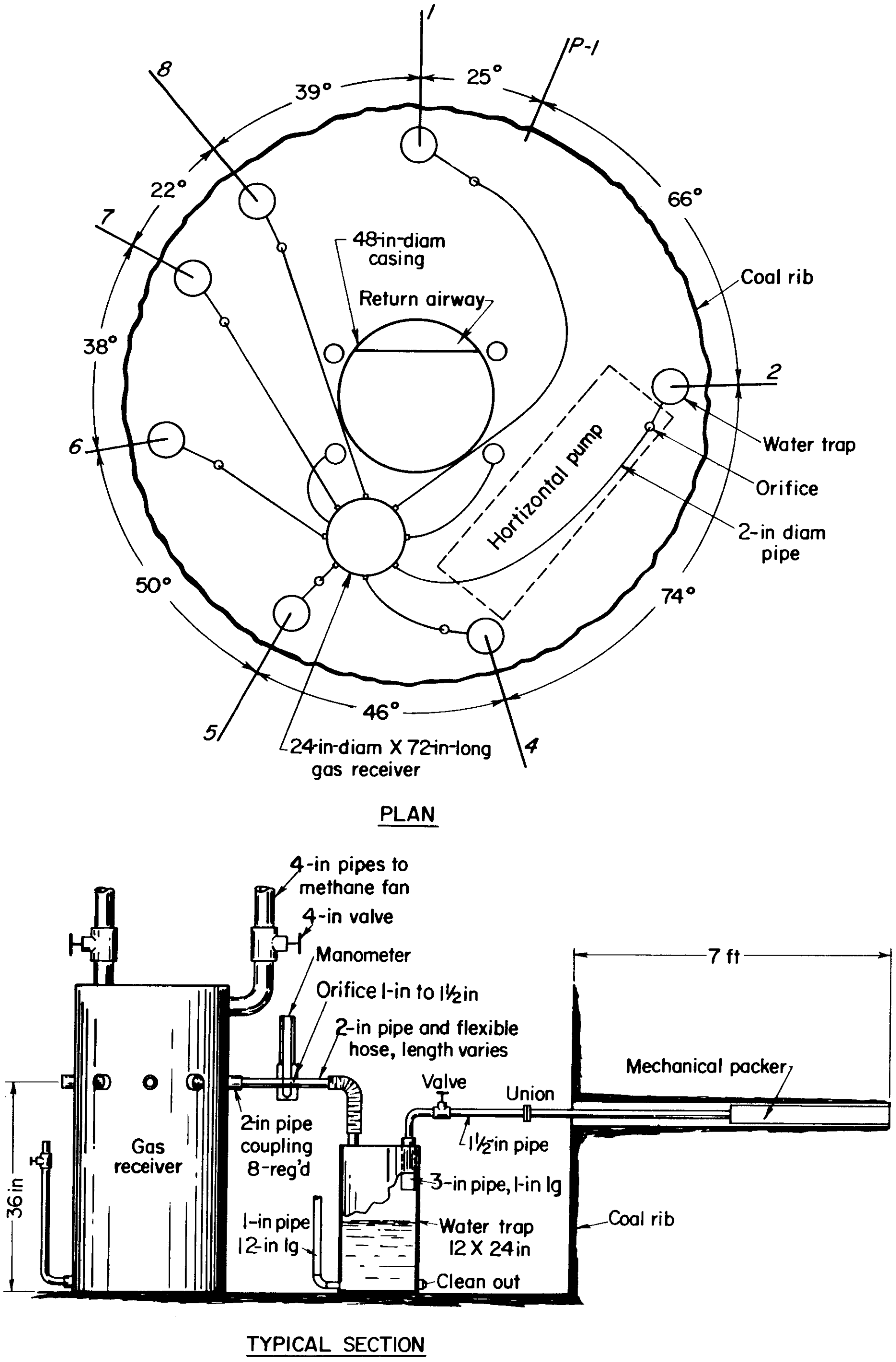

FIGURE 12. - Connection of degasification holes through water traps and receiver tank on bottom.

Dewatering and Degasification

Approximately 10 gpm of water was required to flush cuttings out of each hole drilled in the coalbed (fig. 10). During drilling operations, an air displacement pump was used to remove drill water and cuttings from a sump in the bottom of the large borehole to the surface. Subsequently, the bottom of the large borehole was dewatered by a 50-gpm, submersible pump in a sump powered by a 15-hp, permissible ac motor. A 100-gpm horizontal pump powered by a 40-hp, permissible ac motor was used for standby duty. A few inches of water always covered the bottom of the borehole.

A connection was made from the mechanical packer in each degasification hole to a Bureau-designed water trap at each hole, and then to 24-inch-diameter by 72-inch-high receiver tank. An orifice plate was installed in the pipes between the water traps and the receiver tank for measuring pressure in and flow from each hole. The two 4-inch steel pipes grouted behind the 48-inch casing were connected to the tank (fig. 12).

Figures 8 and 9 show the surface plant layout, including the ventilation, hoisting, and degasification facilities. A Buffalo Forge Co. high-pressure, low-volume blower, model 45-1, type CB, operating at 3,500 rpm and capable of delivering 1,500 cfm of gas at 4 inches of mercury static pressure, was installed to assist in exhausting the gas from the holes in the coalbed. The fan is powered by a direct drive permissible 40-hp ac motor, with variable capacity obtained through a "butterfly" valve arrangement located at the discharge end of the fan. The gas is piped from the receiver tank on the bottom of the borehole through two 4-inch-diameter steel pipes extending to the surface, and connected by a 6-inch-diameter, 100-foot-long, steel pipe to a gas pump. The gas is exhausted through the pump and a 6-inch-diameter, 40-foot vertical pipe, with the gas flow being directed in the direction directly opposite the borehole and the ventilation fan setup. To date, the gas pump has not been used, but will be placed in operation when the total gas flow drops to approximately 350,000 cfd. Total gas flow, pressure, and time are measured by a Rockwell model T-16, 8-inch turbo-flowmeter located on the intake side of the gas pump. Due to the presence of moisture in the gas emitted from the degasification holes, it has been found necessary to insulate the surface piping handling the gas.

All the surface plant ground has been leveled, cleared, graded for good drainage, and covered with a layer of crushed stone, and isolated with a cyclone-type steel fence and two gates. In addition to the ac powerline and facilities previously described, a diesel electric unit has been installed for use in case of the main ac power failure. This spare unit is necessary to prevent excessive flooding of the bottom of borehole in the event of electric power failure.

Figure 13 shows the locations of the degasification holes, the lengths and angles made with respect to the face cleat, and the relationship of the holes to the multipurpose borehole and to the projected set of 10 main headings (3 South Mains).

In situ gas pressure and volume measurements are made periodically (7 to 10 days) at the bottom of the borehole. In addition, total gas flow, pressure, and time also are read with the turbo-flowmeter located on the surface.

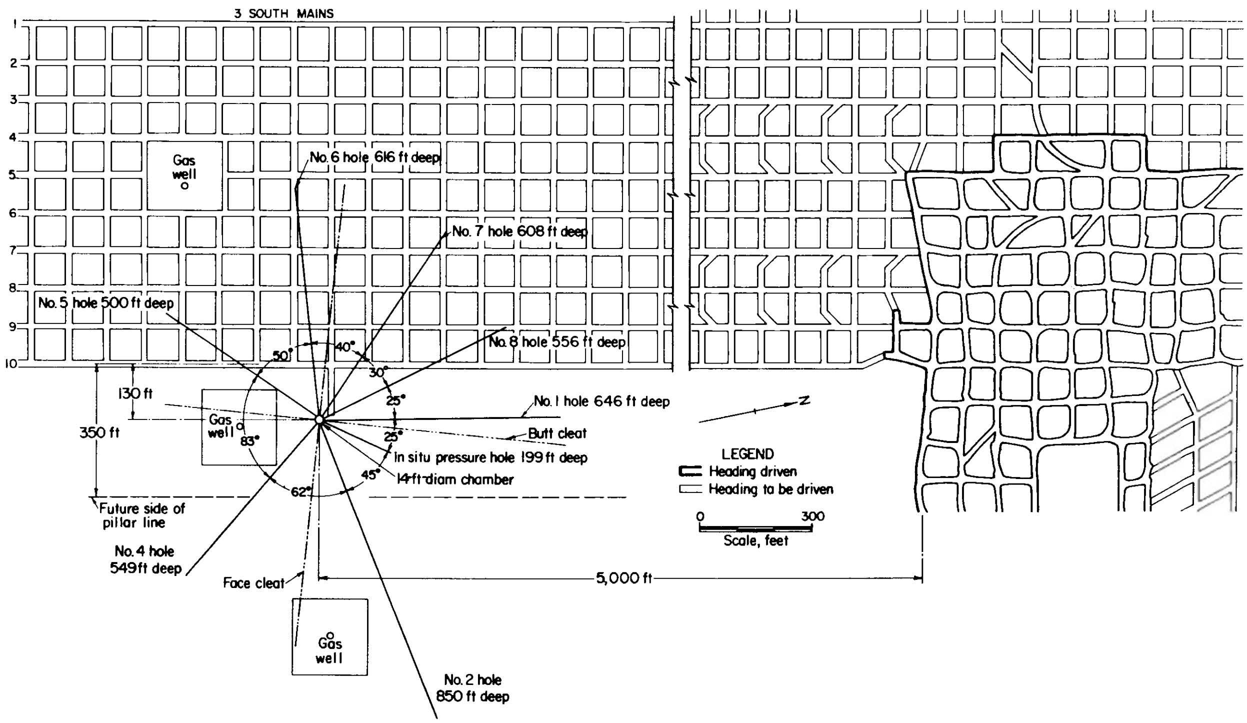

FIGURE 13. - Location of degasification holes underground with respect to closest mine workings to projected main headings and to face cleat.

RESULTS AND DISCUSSIONS

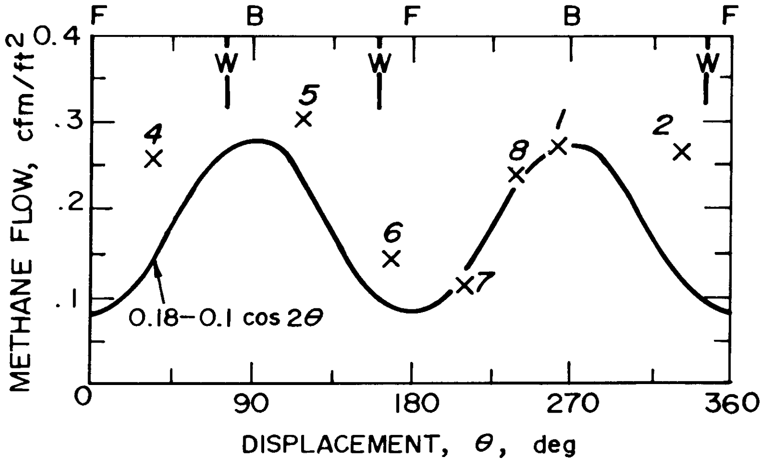

FIGURE 14. - Calculated trend curve of initial gas emission rates from degasification holes.

The initial gas flow rates (obtained during the first 24 hours) from the seven 3-inch-diameter holes drilled in the coalbed from the bottom of the multipurpose borehole are shown in figure 14 and listed in table 1. If we assume that holes 7, 8, and 1 are shielded from the wells by the other holes (particularly 2 and 6), then the initial gas flow rate (GFR) in the absence of the wells would be given by the equation:

$$GFR = (0.18 - 0.1 \text{ Cos } 2\theta) \text{ cfm/ft}^2 \qquad (1)$$

where θ is the angle (displacement) measured clockwise from the face cleat located between holes 2 and 4 (fig. 13). A plot of equation 1 is included in figure 14. Note in particular the effects of the directional permeability on the flow; in the absence of wells, the maximum flow is from holes drilled along the butt cleats (B) and nearly perpendicular to the face cleats (F). However, as boreholes that pass near wells may have flow rates above the predicted values, it is not surprising to find that the initial flow rates from holes 2 and 4 were approximately twice as high as those to be expected from equation 1. Further, comparing the flows from holes 4 and 7 (two diametrically opposed holes), we see that the flow from hole 4, which passes near a gas well, was about 2.5 times higher than that from hole 7, which does not pass near a well. This is in line with earlier findings on the effects of oil and gas wells on emission of methane in coal mines.[9]

TABLE 1. - Initial data on the seven degasification holes

No. of hole[1]	1	2	4	5	6	7	8	Total
Length..........ft..	646	850	549	500	616	608	556	4,325
Gas emission..........(1,000 cfd)..	201	257	159	171	104	79	150	1,121
Gas flow per sq ft of coal surface in holes..........cfd..	396	385	369	435	215	166	344	2,310
Angle of hole with respect to face cleat[2]..........deg..	83.5	28	35	61	12	28.5	59	-
Distance from gas well..........ft..	-	180	160-400	130-370	300	-	-	-
Average water discharge..........gpm..	6.5	6.8	5.6	8.0	5.0	5.0	6.2	43.1
In situ gas pressure at 199-ft depth..........psi..	-	-	-	-	-		-	203

[1]Figure 1.
[2]Face cleat is appreciably more permeable than the much shorter butt cleat.

After the initial flow rates were measured, the seven bleeder holes were connected to a common collector. The flow from each hole is shown in figure 15. The total methane emission from these holes fell for approximately 50 days and then began to increase (table 2). Interestingly, the emission rate fell by a factor of 2 (fig. 16) while the gas pressure in the coalbed fell by a factor of 20 (figs. 17 and 18). However, during this period, a fair amount of water was removed from the coal (the average initial water flow rate was 6.2 gpm per hole; in 50 days this figure fell to 0.5 gpm per hole (fig. 19) and the gas permeability of the coal increased. As a first approximation, the total emission rates (MER) are initially proportional to the increase of the square root of the elapsed time, t:

$$MER = \frac{970}{\sqrt{1 + t/10}}; \quad 0 \leq t \leq 40 \text{ days} \qquad (2)$$

This simple equation yields values within about 5 percent of the smoothed (curve) data given in figure 16.

[9]Zabetakis, M. G., T. D. Moore, Jr., A. E. Nagel, and J. E. Carpetta. Methane Emission in Coal Mines: Effects of Oil and Gas Wells. BuMines RI 7658, 1972, 9 pp.

TABLE 2. - Total gas and water flows and in situ gas pressures

	Gas emission, 1,000 cfd	Average water discharge per hole, gpm	In situ gas pressure, psi
Initial	1,121	6.2	203
Twenty-four hours after all holes connected to collector	971	1.3	190
Days after above 24 hours:			
10	720	1.2	18
20	511	1.2	18
30	464	.8	17
40	444	9.5	11
50	460	.5	10
60	490	.5	10
70	438	.5	13
80	529	.5	13
90	500	.5	13
100	543	.5	13
110	480	.5	13
120	498	.45	12.7
130	515	.43	12.7
140	494	.45	12.7
150	518	.44	12.7
160	509	.34	12.7
170	529	.34	12.7
180	538	.34	12.7

Although 40 million cubic feet of gas was removed in 80 days from the virgin area, the subsequent periodic readings to March 13, 1973 (total of 180 days), showed the volume to have increased to 91 million cubic feet. This is equivalent to an overall average of slightly over 500,000 cfd of gas with the water discharge per hole and in situ pressure dropping to 0.34 gpm and 12.7 psi, respectively, on March 13, 1973. Based on the average depth of holes (618 ft), at least 9,600,000 cubic feet, or 384,000 tons of coal (8-ft coalbed thickness), are involved. Therefore, the total gas emitted per estimated ton of coal in place is 237 cubic feet. This significant volume is approximately 98 percent of the total estimated volume (250 cubic feet) of gas contained in a ton of virgin coal in this general area. Since the daily gas emission rate and in situ pressure were 538,000 cfd and 12.7 psig, respectively, after 180 days of degasification, there is no doubt that gas liberation is occurring beyond the average length of holes.

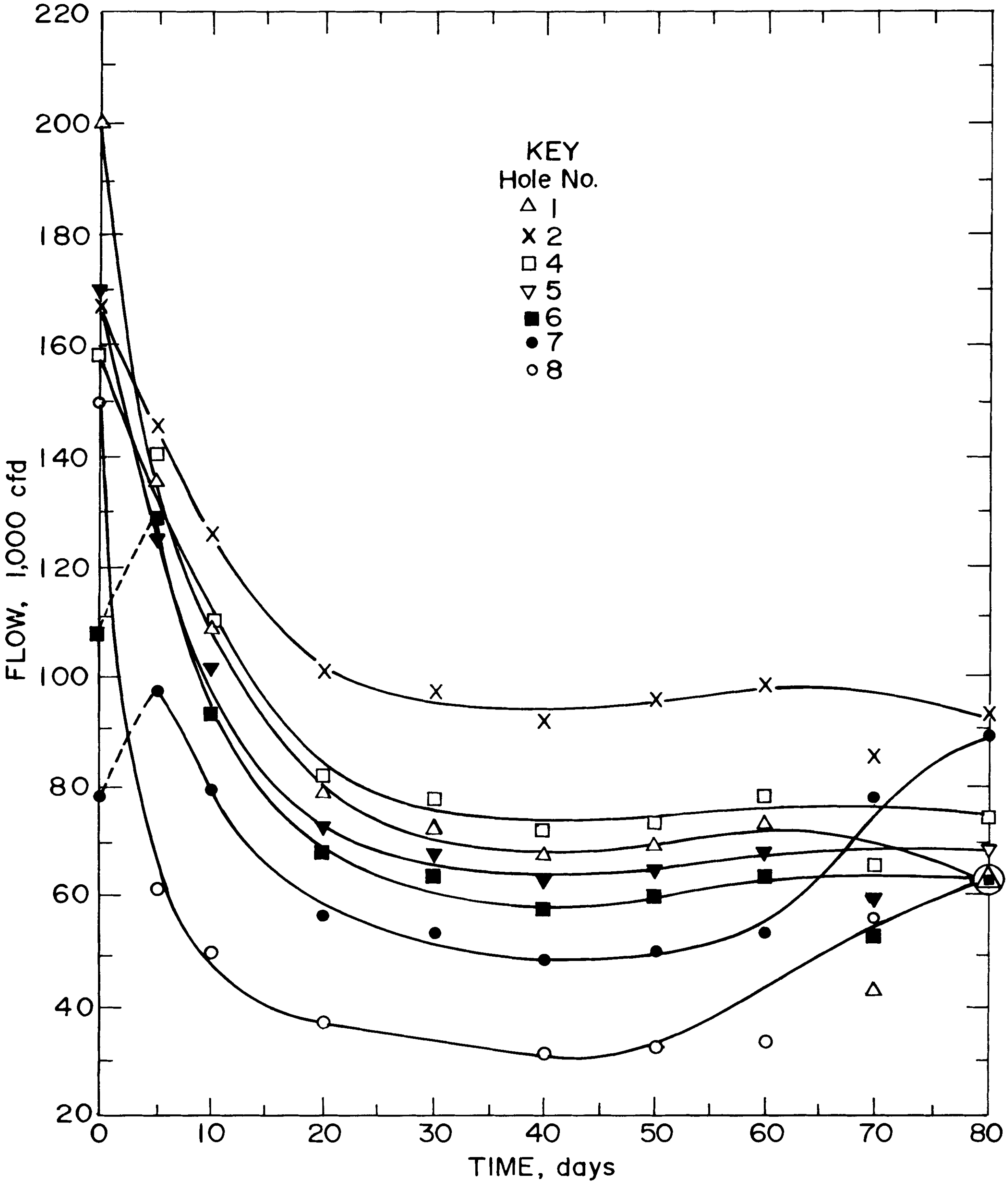

FIGURE 15. - Initial and subsequent gas flow from each hole.

Table 3 shows that 87.7 percent of the gas is methane. When the daily emission rate drops to 350,000 cfd, the gas pump on the surface will be activated to supplement the in situ gas pressure.

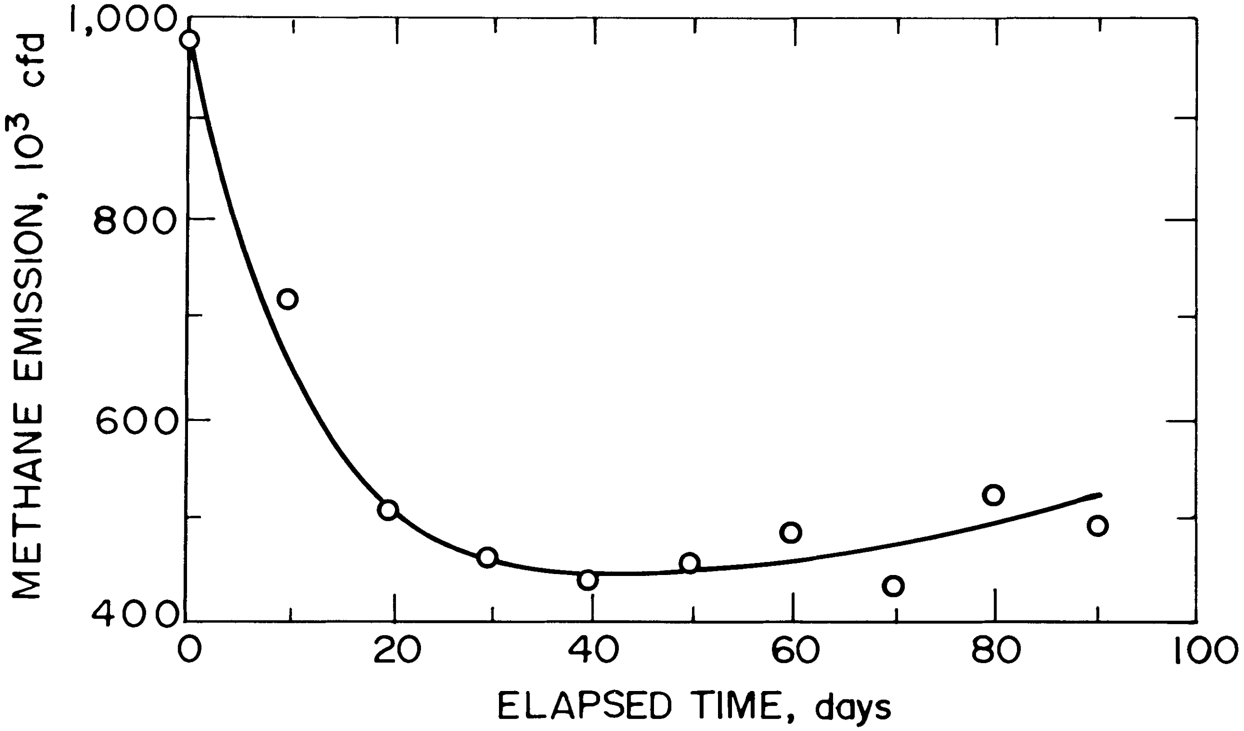

FIGURE 16. - Smooth curve of total gas emission rates (all holes connected to collector).

TABLE 3. - Analyses of two samples from total gas emission

Gas	Sample 1	Sample 2
Ethane (C_2H_6)....................ppm..	300	321
Carbon dioxide (CO_2).............pct..	9.5	9.0
Oxygen (O_2)......................pct..	0.6	1.2
Nitrogen (N_2)....................pct..	2.0	2.4
Methane (CH_4)...................pct..	87.9	87.4

At least 2 years will be required before the 3 South Mains are developed to the multipurpose borehole location. Methane emission will be monitored periodically during development of the mains to determine the actual area of effectiveness of this degasification technique. It is expected that upon maximum practical degasification of the area involved, coal can be mined at normally maximum rate with no hazards from ignitions and explosions, provided normal and properly controlled ventilation is utilized. It is further expected that this situation will prevail some distance from the borehole.

Regarding the cost effectiveness of the degasification technique used in conjunction with the experimental multipurpose borehole, it should be recognized that the expense of this study was quite high. For the depths of the borehole and the degasification holes used here, the total cost was $848,000. Assuming a minimum of 40 minutes' loss of production time per shift in development within virgin coal (this loss has been measured in Federal

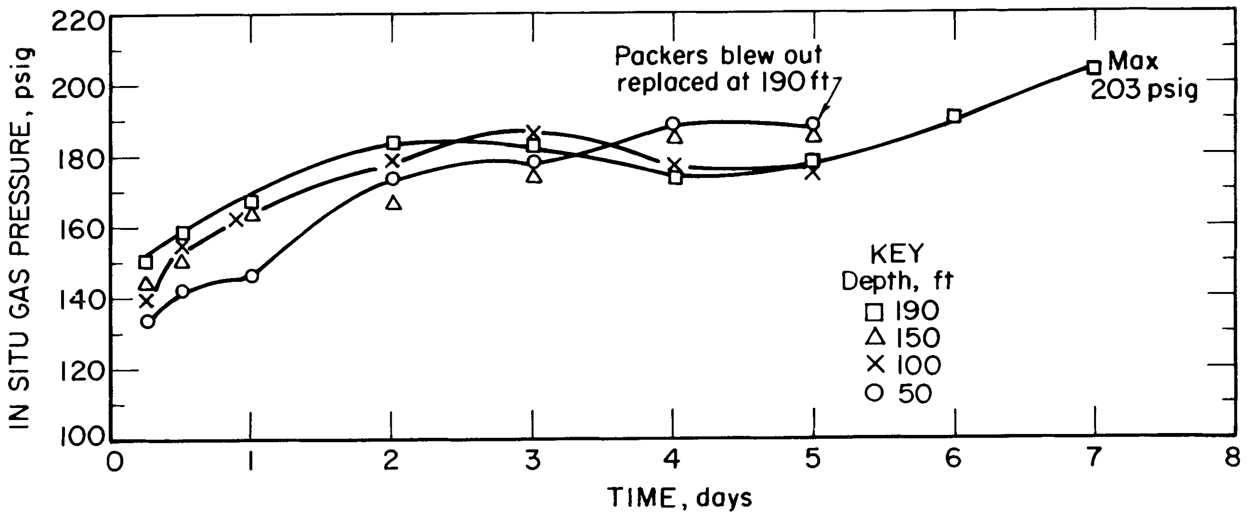

FIGURE 17. - Initial in situ gas pressure (no gas flow).

No. 2 mine because of methane) and an average production rate of 4 tons per minute, 160 tons of coal would be lost per shift. Assuming further that 480 tons of raw coal are produced per shift in the degasified development area, and 320 tons if the area is not degasified, on a clean coal basis, the tonnages would become 410 and 275, respectively. The face costs per shift in both cases would be $450 for a continuous miner operator, a loading machine operator, a ventilation man, two shuttle car operators, mechanic, general serviceman, boom operator, and foreman (all fringe benefits included). The face costs per ton of clean coal would be $1.10 for the degasified area and $1.62 for the nondegasified area, or a difference of $0.52 per ton.

Using 336,000 tons of raw coal (estimated with 7-ft mineable coal thickness) available in the virgin area degasified through the holes drilled in the coalbed (286,000 tons of clean coal), the saving by degasification would be $148,000. It is obvious that the multipurpose borehole is too costly, even if the other progressive uses of the hole are considered.

A much more practical approach is for coal companies operating in very gassy coalbeds to consider planning more air shafts with smaller cross-sectional areas than is the increasing practice today. For example, a 16-foot-diameter, concrete-lined shaft 840 feet deep (same depth as the multipurpose borehole) sunk by mechanized conventional method would cost $650,000 or less. Yearly cost of borrowing this sum at 6 percent interest would be $39,000. Thus, the savings due to this degasification would pay for nearly 4 years' interest. Actually, it would be adequate to sink the shaft 3 years ahead of need and degasify the virgin coal by long holes as accomplished in conjunction with the multipurpose borehole.

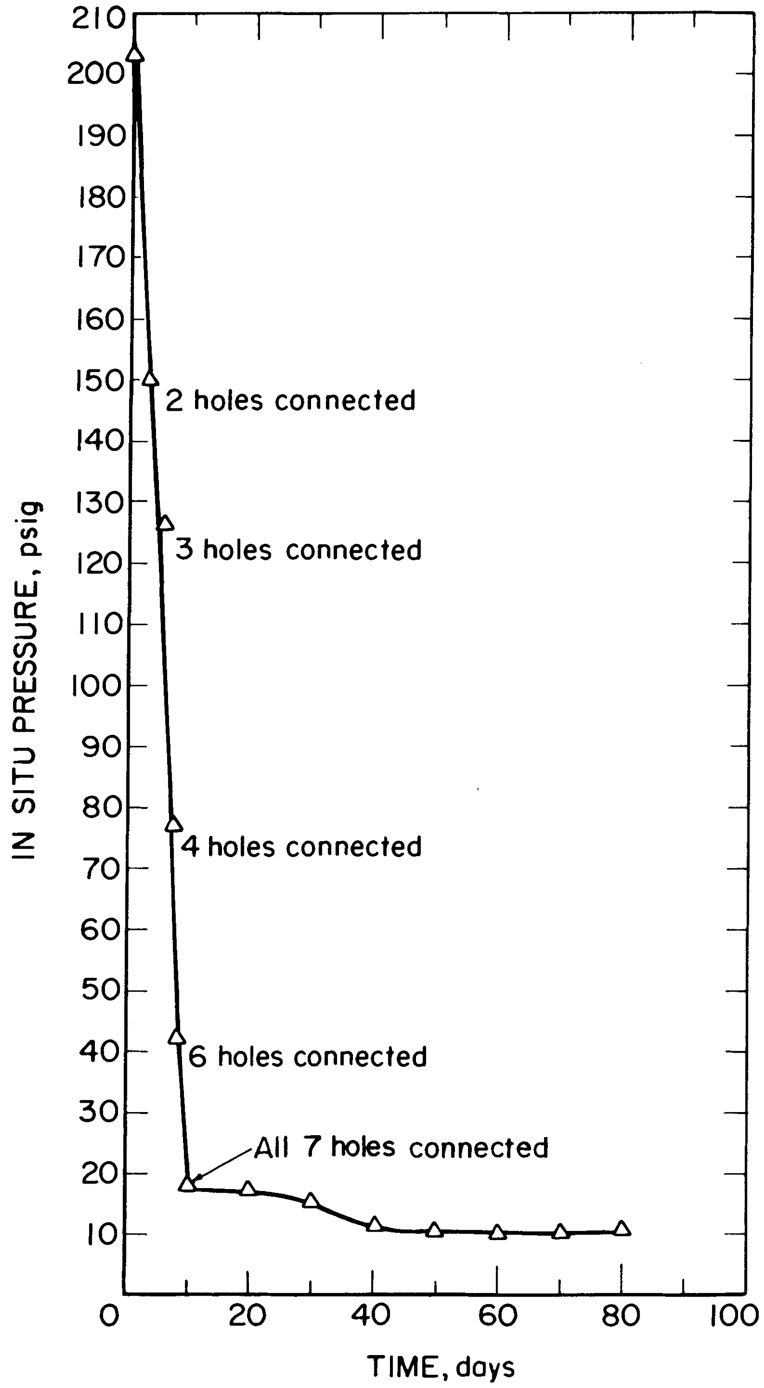

FIGURE 18. - In situ gas pressure (after flow was established).

Other benefits would accrue as a lesser number of headings should be required between air shafts (these should be maintained in an open condition to the fullest extent practicable) and from the possibility of isolating major panels of coal for at least 1 year and preferably 2 years for gas bleed off prior to mining within the panels. It is not intended to imply that air shafts should be sunk on approximately 2,000- to 3,000-foot centers, but rather to carefully plan the layout of sets of main headings in the whole mine and determine the locations of both intake and return air shafts required for ventilation purposes and additional air shafts with the intent of degasifying the coalbed from the bottom of each. It may be found advisable to sink some shafts 14 feet in diameter. Two compartment shafts, in the opinion of the authors, are questionable from the standpoints of safety and cost, except possibly in some very unusual cases. In case of a catastrophe, destruction of the curtain wall at the bottom would render the shaft useless; and if two shafts were sunk approximately 300 feet apart with the two open cross-sectional areas equaling those in the two compartments, there would be a relatively small difference in the total cost.

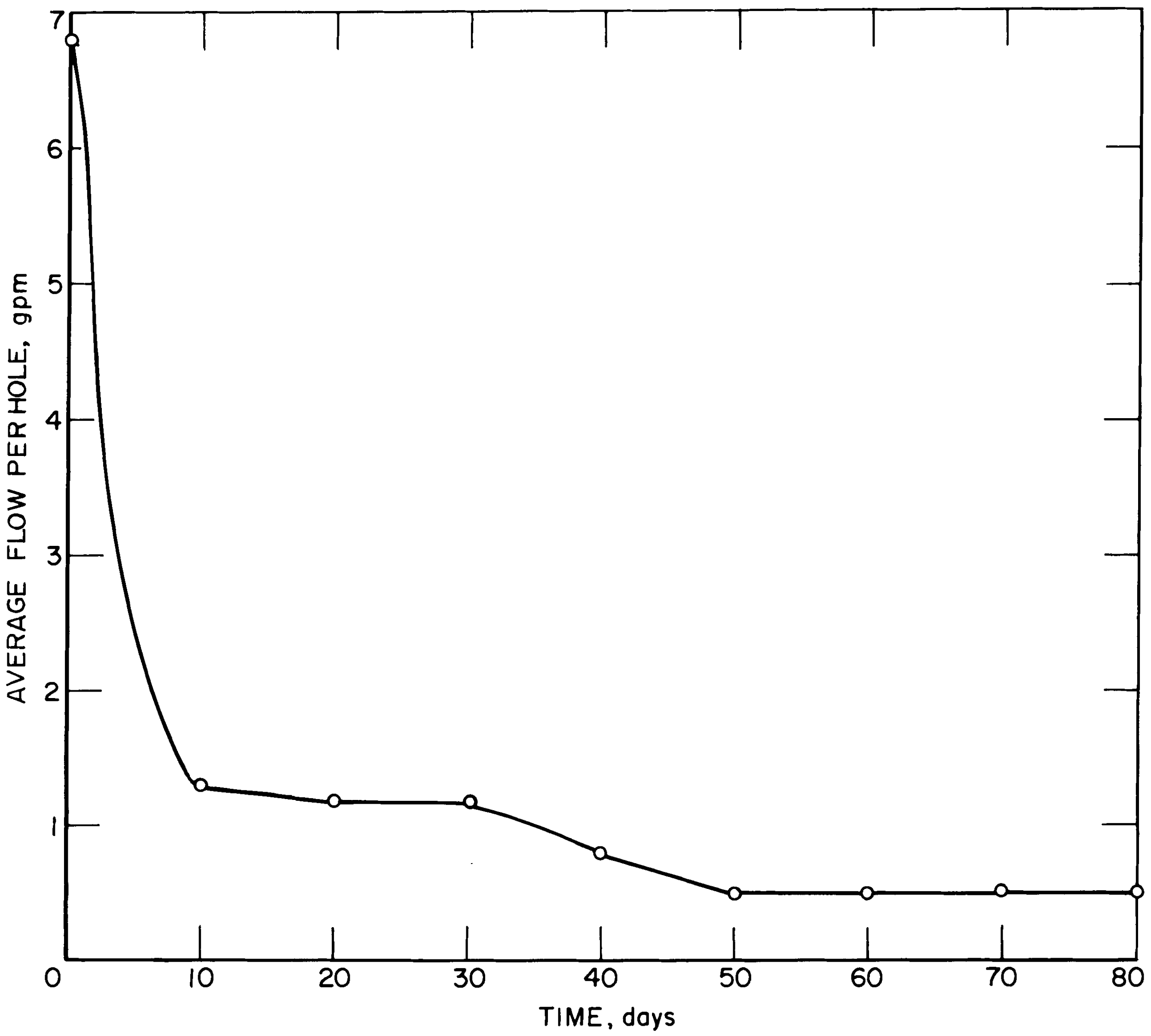

FIGURE 19. - Average water flow rate per hole.

CONCLUSIONS

Based on the results obtained in 180 days, it can be concluded that the multipurpose borehole is a useful degasification technique. It is very probable that the final degasification will exceed appreciably 70 percent of the estimated volume of gas contained in 1 ton of virgin Pittsburgh coalbed. However, the multipurpose borehole is quite expensive; therefore, it appears advisable to consider using the technique of drilling degasification holes in the coalbed from the bottom of planned air shafts (sunk by conventional mechanized methods) in virgin coal areas approximately 3 years ahead of closest mine workings.

APPENDIX.--DRILLING EQUIPMENT

The shaft drilling equipment used here was Loffland Brothers rig No. 142. This is a specialized drilling rig designed exclusively for shaft drilling operations. The major rig components are listed below:

Derrick:	Lee C. Moore; mast 133 feet; 750,000-lb capacity.
Substructures:	Lee C. Moore; 12 feet 4 inches; 450,000-lb casing capacity; 300,000-lb setback capacity.
Draw works:	National 75; maximum single line pull 27,330 lb; maximum hook load, 10 lines, 576,000 lb.
Auxiliary brake:	Parkersburg 40-inch double hydromatic.
Engines:	Four Cummins N855-P250; 440 int. kW at 1,750 rpm and 240 cont. kW at 1,750 rpm driving four Reliance 640 pm dc generators.
Desander:	San Angelo 12-cone (three units of four cones each).
Water storage:	To comply with bid specifications.
Generators:	Two, 37.5 kV-A ac each.
Rotary table:	National 27-1/2-inch.
Traveling block:	National 5 sheave, 300-ton.
Crown block:	Lee C. Moore.
Hook:	Byron Jackson Model 4200, 200-ton.
Swivel:	High B. Williams, 250-ton, 12-inch ID.
Special tools:	All necessary shaft drilling equipment including: 1. Drill pipe, 13-3/8-inch OD. 2. Drill collar and stabilizers, 40-inch. 3. Flat bottom bits, 84- and 72-inch. 4. Casing running tools.

Supporting equipment:

1. Input draw works, 1,000-hp, 6-speed.

2. AC powerhouse.
   One ac distribution panel.
   One 4 ac air compressor.
   Two 671 CMC 125-hp.
   One generator, 50-kW ac.

3. Draw work motors.
   Two 400-hp Reliance dc motors.

4. Oil rotary table, 27-1/2-inch, with 3.85 to 1 reduction.

5. DC powerhouse.
   Four NH 250 Cummins 250-hp diesel drive engines with four 4,000-hp Reliance dc generators.
   Engine 1, used only for draw works.
   Engine 2, used for draw works, mud pumps, or sandline for survey.
   Engine 3, used only for mud pumps.
   Engine 4, used only for rig air compressor.

6. Air compressor.
   Two 750 Joy air compressors driven by two 12-V 71 250-hp General Motors Corp. motors.

7. Mud pumps.
   Two 14- by 16-inch Allen Sherman rotary pumps driven by two 400-hp Reliance motors.

8. DC switch gear.
   Electrical controls for standby operations.
   Main electrical controls for normal operations.
   Ground operator's control panel.

9. Rig air compressor.
   One 600-cfm I.R. air compressor driven by one 400-hp Reliance motor.

10. Water pump.
    One 2-foot by 3-inch B.J. pump driven by one 20-hp ac motor.

11. Sandline.
    One 15,000-ft 5/16-inch wire line driven by one 400-hp Reliance dc motor.

12. Drill line spool.
    One spool with 7,500 feet of 1-3/8-inch wire rope.

13. Fuel tank.
    One 5,000-gal fuel tank with 2-inch pump.

14. Power pole.
    One power pole with three 440-V three-phase ac output 100-kW transformers.

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